Laminated Ceramic Components For Microreactor Applications

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Motivation

- Ceramic materials needed for
  - High temperature operation of microreactor devices
  - Operation of microreactor devices in corrosive environments
  - Microscale Chemical And Thermal Systems (MICRO-CATS)

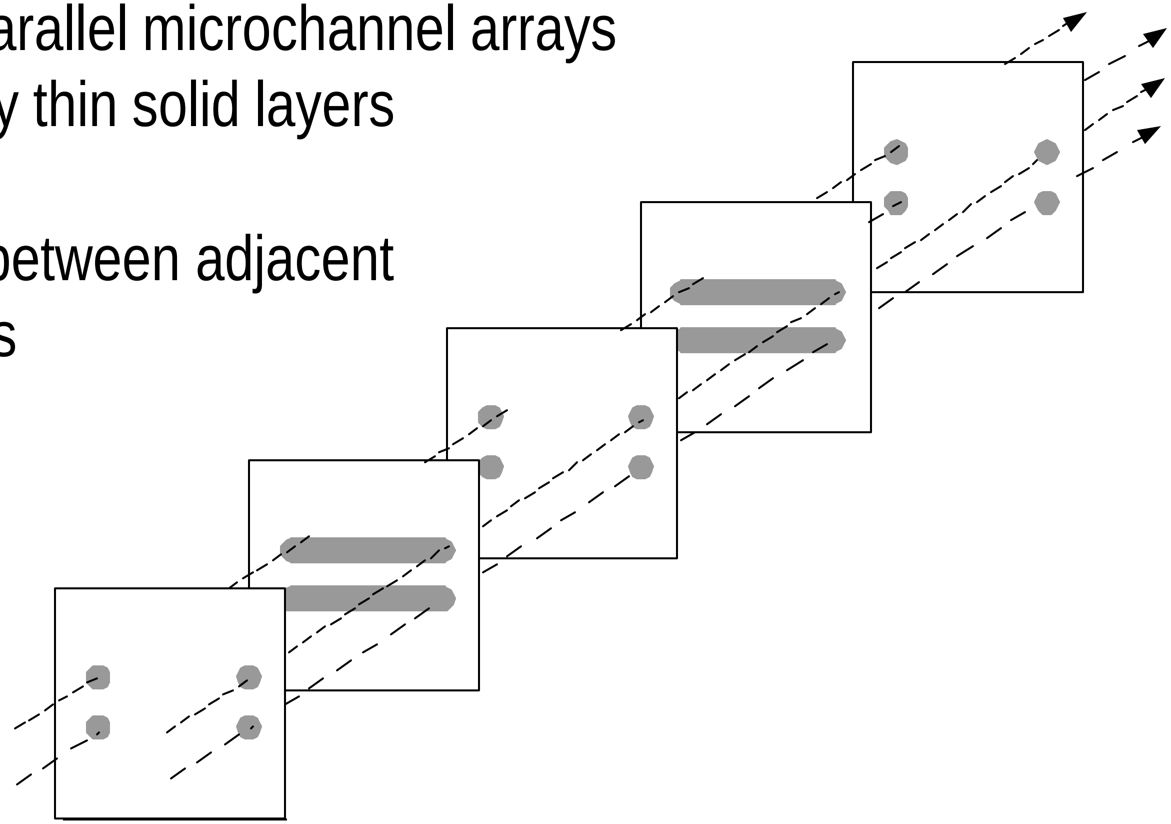
- Low-cost production-amenable fabrication process for ceramic microreactor components needed

Assembly Diagram For a Simple Microchannel Device

Consists of

- laminated parallel microchannel arrays
- separated by thin solid layers

Heat transferred between adjacent arrays of channels



Ceramic Laminates

- Green ceramic tape (Ferro type A6-C-10)
- 125 to 250-µm thick (unfired)
- Prototype laminates cut by CO_2 laser
- Stamping of laminates would be used in production environment

Fabrication Steps for Ceramics

- Device design
- Shim patterning
- Shim assembly
- Bonding
- Post-bonding

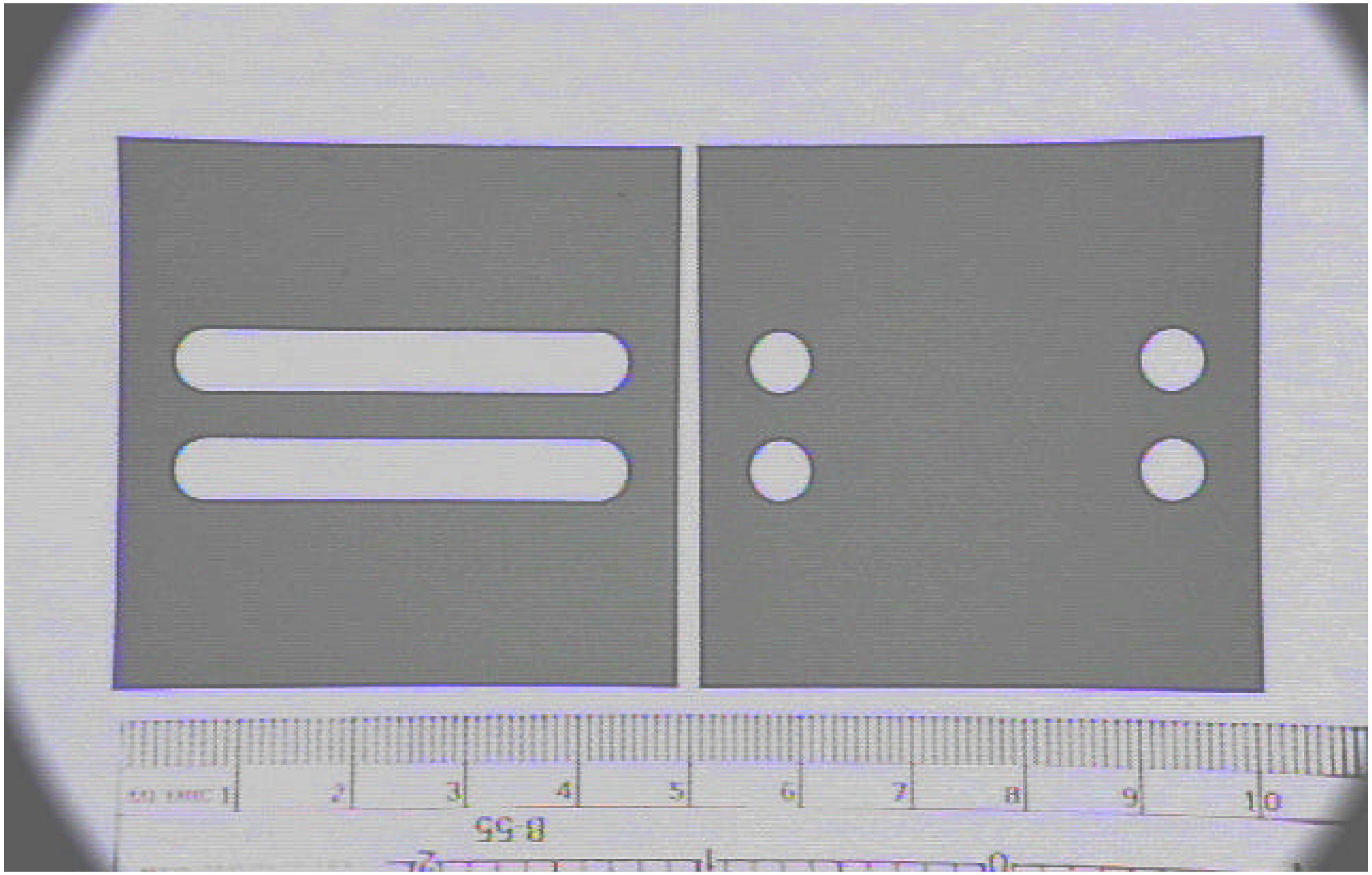
Shim Patterning

- Patterns must be cleanly cut, burr-free
- Laser cut for prototypes
- Stamped for production mode
- Can even be patterned with hobby knife

Shim Design

- Dimensions of internal microchannel are determined by:
  - material thickness
  - length and height of channel cutout
- Sagging issues
  - smaller channel height
  - sacrificial filler material
- Shrinkage factor
  - same material for fins and channels
  - compatibility of different materials

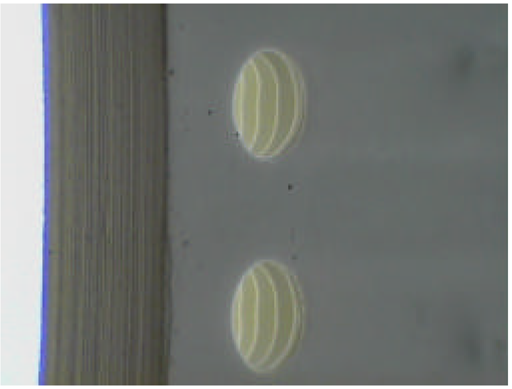
Laser-Machined Green Ceramic Laminates



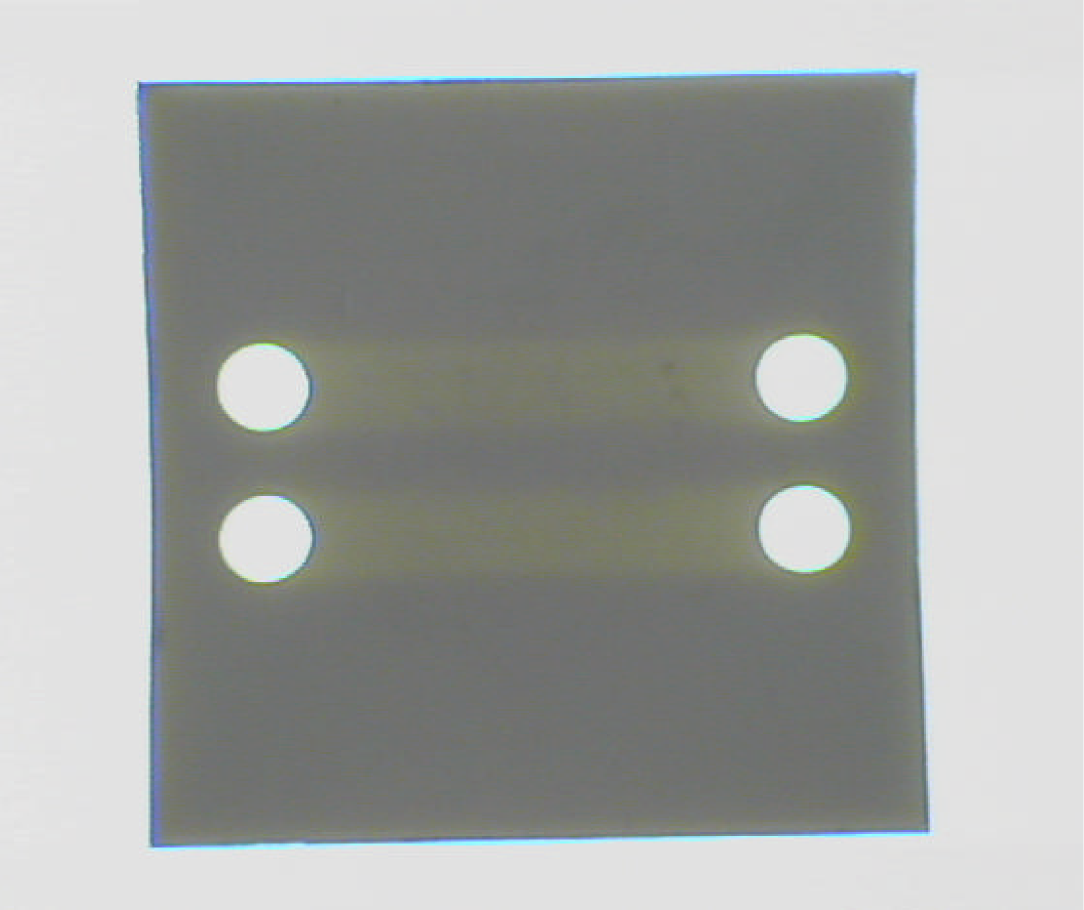
a) Channel shim b) Fin shim

Laminated Ceramic Microchannel Device

- Green ceramic tape laminates (Laser machined)
- 10 channel shims
- 11 fin shims
- Two parallel channels



View through header ports showing microchannel details



(backlit to show channels)

3-Step Lamination Process

1) Precondition individual laminates

2) Stack and press

3) Heat treat entire unit

Ceramic Lamination Processes - Steps 1 & 2

Step 1: Precondition

- Bake individual laminates at 50°C for 20-30 min

Step 2: Stack and Press

- Performed using hydraulic press with heated platens
- Stack laminates
- Uniaxially pressed at 2000 psi and 70°C for 10 min

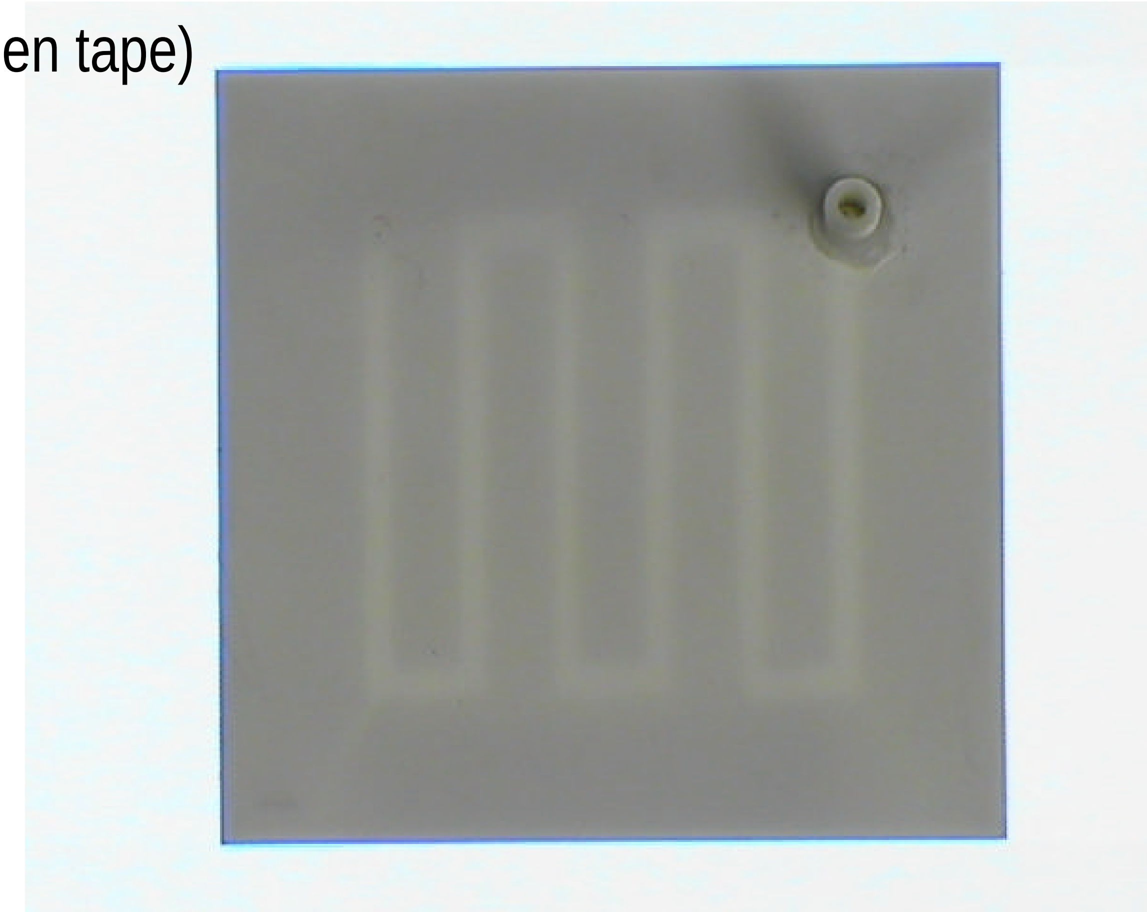
Ceramic Lamination Process - Step 3

Heat treatment performed in box furnace:

- Ramp temperature at 1°C/min to 400°C
- Soak 2 hr at 400°C (longer soak times were required for parts thicker than ~3/8” to fully remove binder from the stack)
- Ramp temperature at 5°C/min to 875°C
- Soak at 875°C for 30 min
- Cool to room temperature

Laminated Ceramic Microchannel Device

- Green tape (hand cut)/Alumina stack
- 4 channel shims (Green tape)
- 5 fin shims (Alumina)
- Serpentine channel
- Inlet and outlet tubes epoxied in place



(backlit to show channels)

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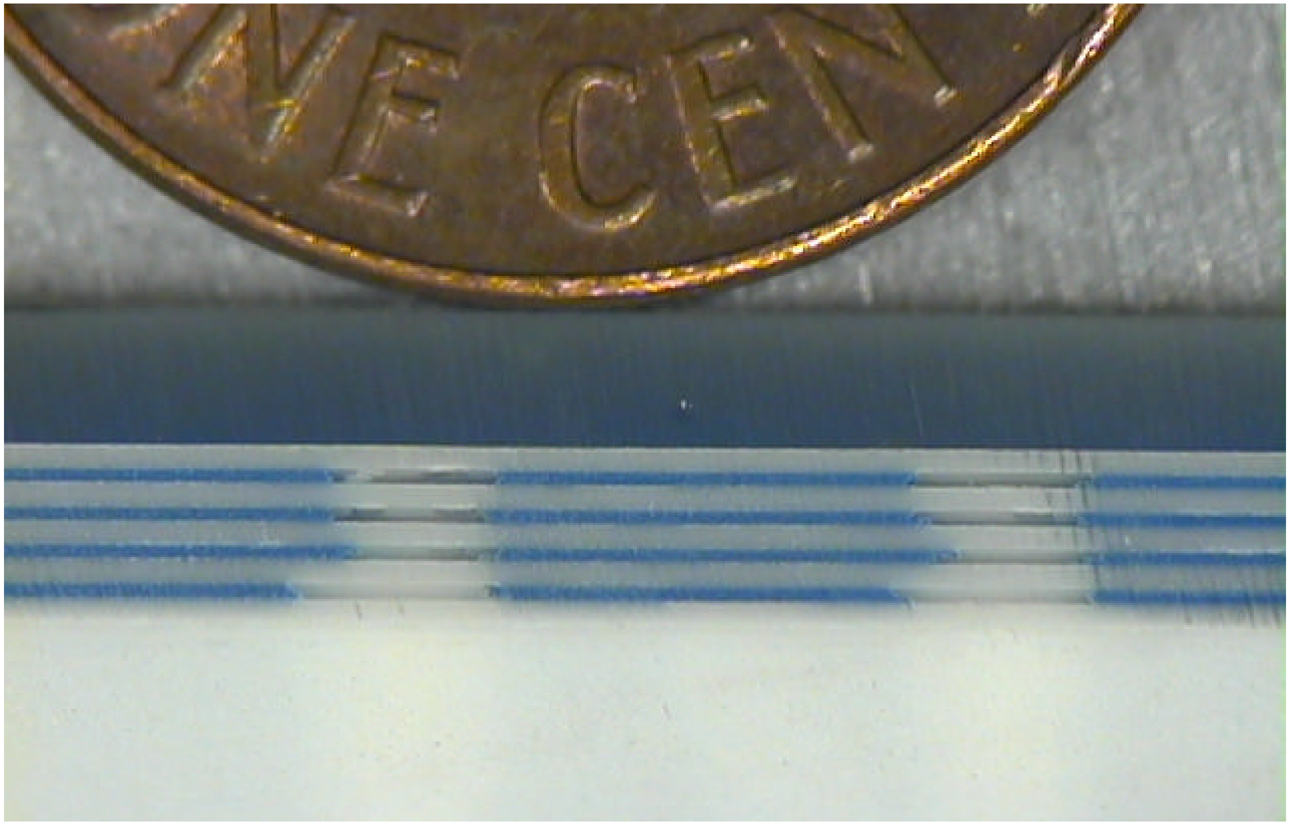
Cross-Section of Flow Channels

- Green tape (hand cut)/Alumina stack
- 4 channel shims (Green tape: blue layer)
- 5 fin shims (Alumina: white layer)



Post-Bonding

- Inlet and outlet tubes attached using high-temperature epoxy
- Machining of excess material may be required for some designs

Summary

- One-piece ceramic microchannel devices produced by a lamination/bonding process
- Commercially available green ceramic tape patterned to form individual shims
- Patterning done by hand or laser machining
- Bonding done without vacuum or inert atmospheres
- Leaktight
- Material issues to be fully resolved include shrinkage and sagging

Summary

- PNNL continuing evaluation of ceramic lamination and bonding processes
- Ongoing needs for novel MICRO-CATS applications
  - http://www.pnl.gov/microcats
- Future ceramic efforts include
  - heat exchangers
  - catalyst supports for high-temperature reactors

Advantages

- Green ceramic tape may be patterned by
  - laser
  - ultrasonic
  - punching
  - dicing
- No oxide layer removal needed
- Work outside vacuum or inert gas environment during bonding

Material Issues

- In green state, tends to sag
- Sacrificial material may be needed to prevent sagging
- Large height-to-width ratios should be avoided if part orientation would allow fins to sag into channels without sacrificial material
- Shrinkage is inherent during bonding/firing process
  - ~12.5% in x and y direction
  - ~15% in z direction

Laminated Microchannel Devices

- Unique lamination and bonding process developed by PNNL
- Capability to produce solid devices with complex multilayer internal microstructures
- Range of materials include
  - metals
  - plastics
  - ceramics